TITLE OF THE INVENTION

TOOTH MOBILITY MEASURING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the
benefit of priority from the prior Japanese Patent
Application No. 2002-204637, filed July 12, 2002,
the entire contents of which are incorporated herein
by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a tooth mobility
measuring apparatus which measures the tooth mobility
of a tooth to determine the state of the tooth.

2. Description of the Related Art

Tooth mobility measurement is done to diagnose
a tooth and the state of a tooth (e.g., the state
of periodontal tissue that supports a tooth).
Conventionally, a subjective measuring method has been
used in which the tooth mobility is grasped on the
basis of inspection, palpation percussion, the moving
states of teeth, and the like. This method however
largely depends on the subjectivity of the operator.
In addition, since this method gives importance to
only the displacement amount of a tooth, properties
such as the viscoelasticity of periodontal tissue
may not be made clear. To objectively determine the
tooth mobility, a tooth mobility measuring apparatus

disclosed in Jpn. Pat. Appln. KOKAI Publication

No. 4-279157 has been developed. As shown in FIG. 1,

this tooth mobility measuring apparatus hits a tooth

with a hammer 4, catches with a sensor 3 the variation

5   of the tooth that fluctuates upon being hit, extracts

the variation as an electrical signal, and calculates

the tooth mobility of the tooth on the basis of the

electrical signal.

FIG. 2 shows another apparatus. This apparatus

10   causes a pick 26 to fly through a cylinder 29 using the

force of a spring 27 to make an impact on a tooth 28.

The conventional measuring apparatus described

in Jpn. Pat. Appln. KOKAI Publication No. 4-279157

measures the acceleration of displacement of a tooth.

15   The acceleration is measured by bringing the hammer

into direct contact with the tooth, and the tooth

mobility is measured on the basis of the acceleration.

Hence, for accurate measurement, the hammering position

on the tooth must be accurate. In addition, hammering

20   must be done with an appropriate force. If the

hammering force is too strong, the patient may feel

a pain. The conventional apparatus shown in FIG. 2

executes automatic hammering. For this reason, the

magnitude of load is stable, and the hammering force

25   is unlikely to be too strong. However, patients whose

teeth and periodontal tissue are not in a good state

may feel pain upon hammering. Furthermore, since the

acceleration of the hammer changes according to the tilt of the apparatus, the magnitude of load may change and influence the measuring accuracy.

BRIEF SUMMARY OF THE INVENTION

5   The present invention has been made in consideration of the above situation, and has as its object to provide a tooth mobility measuring apparatus which may measure tooth mobility by achieving at least one of accurately measuring at least one of the displacement 10   and tooth mobility of a tooth without bringing a measuring tool into contact with the tooth and easing the pain felt by a patient. In this specification, the term "tooth" includes an artificial tooth, such as a dental implant, as well as a natural tooth.

15   According to an aspect of the present invention, there is provided a tooth mobility measuring apparatus comprising: an impact mechanism which has at least one of an injection mechanism having an injection port which injects a fluid and a suction mechanism having 20   a vacuum port which sucks air, and applies an impact force on a tooth by injection or suction, the impact mechanism comprising a control mechanism which sets a pressure by injection or suction to a predetermined value; at least one sensor which detects a displacement 25   state of the tooth which is moved by the impact force of the impact mechanism; and a tooth mobility calculation mechanism which calculates a tooth mobility of the

tooth on the basis of an output signal from the sensor.

In this apparatus, the fluid is preferably a gas.

In this apparatus, the gas is preferably air.

In this apparatus, preferably, the injection

5 mechanism or suction mechanism has a nozzle, and the
nozzle has a structure adapted to the arrangement and
form of the tooth to be inspected.

In this apparatus, the object to be measured
simultaneously preferably comprises one or a plurality

10 of teeth.

In this apparatus, the control mechanism may
preferably variably adjust the predetermined value.

In this apparatus, the injection mechanism
preferably further comprises a temperature adjusting

15 mechanism which adjusts the temperature of the fluid.

In this apparatus, the injection mechanism may
preferably adjust at least one of an injection state,
a number of times of injection, and an injection timing
of the fluid to be impactively injected to the tooth to

20 be inspected.

In this apparatus, the sensor is preferably a
measuring device which senses at least one of a change
in vibration of air and a change in electrostatic
capacitance between the injection port or vacuum port

25 and the tooth surface to detect the displacement state
of the tooth.

In this apparatus, the sensor is preferably

a measuring device which irradiates the tooth with light and detects the displacement state of the tooth on the basis of reflected light.

In this apparatus, the light of the sensor is preferably a laser beam.

In this apparatus, the light output from the sensor also preferably has a position confirming function to visually recognize a position of a target to be subjected to injection or suction by the impact mechanism.

In this apparatus, the sensor is preferably arranged around the injection port or the vacuum port.

In this apparatus, the displacement state of the tooth to be detected is preferably at least one of a displacement amount and a displacement time of the tooth to be inspected.

In this apparatus, the tooth mobility calculation mechanism preferably calculates an acceleration of displacement of the tooth on the basis of a maximum displacement amount and a displacement time of the tooth to be inspected.

In this apparatus, the tooth mobility calculation mechanism preferably calculates the tooth mobility of the tooth to be inspected on the basis of at least one of the injection pressure or suction pressure for the tooth, the maximum displacement amount of the tooth, the displacement time of the tooth, and the distance

between the injection port or vacuum port of the impact mechanism and the tooth to be inspected.

In this apparatus, the tooth mobility measuring apparatus preferably further comprises at least one of a storage device which stores the calculated tooth mobility, a display mechanism which displays the tooth mobility, and an output mechanism which prints the tooth mobility on a paper sheet.

In this apparatus, the tooth mobility measuring apparatus preferably further comprises means for locating the injection port or the vacuum port with respect to the tooth to be inspected.

According to another aspect of the present invention, there is provided a tooth mobility measuring method comprising steps of: (a) applying an impact force having a predetermined pressure on a tooth to be inspected, the impact force being applied by one of injecting a fluid having a predetermined pressure to the tooth to be inspected and sucking the tooth to be inspected at a predetermined pressure; (b) detecting a displacement state of the tooth which is moved by the impact force; and (c) calculating a tooth mobility of the tooth on the basis of the detected displacement state.

In this measuring method, the fluid in the step (a) is preferably a gas.

In this measuring method, the gas in the step (a)

is preferably air.

In this measuring method, the step (a) preferably further comprises a step of adjusting the pressure of the fluid.

In this measuring method, the step (a) preferably further comprises a step of adjusting the temperature of the fluid.

In this measuring method, the step (b) preferably comprises a step of adjusting at least one of a stress form of the impact, a number of times of impact, and a timing of application of the impact force.

In this measuring method, the step (a) preferably further comprises a step of locating an injection port or a vacuum port to a predetermined position using means for locating the injection port or the vacuum port with respect to the tooth to be inspected.

In this measuring method, the step (b) preferably comprises a step of irradiating the tooth with light and detecting the displacement state of the tooth on the basis of reflected light.

In this measuring method, the step (b) preferably comprises a step of detecting the displacement state of the tooth from at least one of a displacement amount and a displacement time of the tooth to be inspected.

In this measuring method, the step (c) preferably comprises a step of calculating the acceleration of displacement of the tooth to be inspected on the basis

of the maximum displacement amount of the tooth and the displacement time of the tooth.

In this measuring method, the step (c) preferably comprises a step of calculating the tooth mobility of the tooth to be inspected on the basis of at least one of the impact force applied to the tooth, a maximum displacement amount of the tooth, a displacement time of the tooth, and a distance between an injection port or a vacuum port and the tooth to be inspected.

In this measuring method, the step (c) preferably comprises at least one of a step of storing the calculated tooth mobility, a step of displaying the tooth mobility, and a step of outputting the tooth mobility to a paper sheet.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate presently preferred embodiments of the invention, and together with the general description given above and the detailed description of the preferred embodiments given below, serve to explain the principles of the invention.

FIG. 1 is a circuit diagram of a conventional tooth mobility measuring apparatus;

FIG. 2 is a view showing the principle of another conventional tooth mobility measuring apparatus;

FIG. 3 is a view showing an embodiment of a tooth

mobility measuring apparatus according to the present
invention;

FIG. 4 is a front view of an injection port at
a nozzle distal end portion;

5   FIG. 5 is a front view at another nozzle distal
end portion; and

FIG. 6 is a front view at still another nozzle
distal end portion.

DETAILED DESCRIPTION OF THE INVENTION

10   The present invention will be described below on
the basis of an embodiment shown in FIGS. 3 to 5.
Referring to FIG. 3, a tooth mobility measuring
apparatus 30 comprises an impact mechanism 42 having
an injection mechanism 43 with an injection port 38

15   for injecting a fluid (e.g., a liquid or a gas) to
a tooth 28 or a suction mechanism 43' having a vacuum
port 38' for sucking air, a sensor 35, and a tooth
mobility calculation mechanism 44.

A case wherein the impact mechanism 42 has the

20   injection mechanism will be described below. On the
basis of this description, a person skilled in the art
may also easily understand and practice a case wherein
the impact mechanism has the suction mechanism.

The injection mechanism 43 may have a fluid

25   compressor 31, a nozzle 34 which injects a fluid to
a tooth, an elastic tube 33 which connects the fluid
compressor 31 to the nozzle 34, and a control mechanism

41. A valve 32 may be arranged midway along the tube
33. The fluid injected by the injection mechanism 43
may be a gas, a liquid, or a mixture thereof.

A gas and, more particularly, air is preferably
5   used from the viewpoint of ensuring easy handling
and measuring accuracy. When a gas is used as the
pressurized fluid, handling is easy. In addition,
since the surface of the tooth may be kept in a state
suitable for measurement, the measuring accuracy
10   increases. When air is used as the pressurized fluid,
no gas cylinder needs to be prepared, and no cost is
required to prepare a specific gas such as nitrogen
or carbon dioxide, resulting in advantage in terms
of space and cost. On the other hand, when a liquid
15   (e.g., water) is used as the pressurized fluid,
handling is relatively easy, and a predetermined impact
force may be ensured by injection at a pressure lower
than that for a gas. The fluid injected by the
injection mechanism 43 will be referred to as a gas
20   hereinafter.

The fluid compressor 31 pressurizes the gas to
a predetermined pressure and outputs the gas to the
nozzle 34 through the tube 33. The tube 33 may have
midway therealong the valve 32 which controls the flow
25   of the pressurized gas. As the valve 32, any mechanism
may be employed as long as it may be ON/OFF-controlled
by hand or foot. For example, a solenoid valve may be

employed as the valve 32. When the solenoid valve is employed, the operator may accurately and easily open/close the valve by ON/OFF-controlling a switch 36 disposed, near him or on the measuring apparatus main body, by hand or foot.

When the open/close speed, the open/close time, and the degree of open/close of the valve 32 are controlled to predetermined values by the electro-magnetic force, the stress form of the impact, i.e., the injection state of the injected gas (e.g., the pressure, injection amount, injection time) may be controlled. As the injection a pulsed or sinusoidally-varying injection may be employed. The switch may turn on/off a controller 37 for controlling the open/close of the valve 32.

The fluid compressor 31 may also have a tempera-ture adjusting device which adjusts the temperature of the fluid to be output. The temperature adjusting device adjusts the gas to a predetermined temperature to prevent pain in the tooth caused by the temperature difference between the injected gas and the tooth.

The nozzle 34 injects the compressed gas output from the fluid compressor 31 to the tooth to be inspected through the valve 32. The nozzle 34 preferably has a structure that can make an operator easy to operate and can make an accurate gas injection to a tooth in the measurement. For this purpose,

various shapes of nozzles may be employed. For
example, to measure a front tooth, the distal end of
the nozzle preferably has a straight shape, as shown in
FIG. 3. On the other hand, to measure a back tooth,
the distal end of the nozzle preferably has, e.g., an L
shape.

Such shapes may be realized by exchanging the
nozzle distal end portion in correspondence with the
object to be inspected. Alternatively, the shapes may
be realized by employing a nozzle distal end portion
having a bendable structure. The shapes may be
realized by covering the nozzle distal end portion with
a cap having a predetermined shape. The nozzle 34
shown in FIG. 3 may be constituted by a grip portion
34a and distal end portion 34b. The grip portion may
have the switch 36 which ON/OFF-controls the valve 32
or controller 37. The switch may be a foot switch.
The valve 32 which turns on/off injection of the
pressurized gas formed by the fluid compressor 31 and
sent through the tube 33 may be arranged in the grip
34a. The valve 32 may be arranged in either the nozzle
34 or the tube 33. From the viewpoint of ensuring
quick response of valve operation, the valve is
preferably arranged at a position closer to the distal
end portion 34b.

The distal end portion 34b of the nozzle 34 may
have a tapered shape continuously from the grip 34a.

The distal end portion may have the circular injection
port 38, as shown in FIG. 4 or 5. A shape other than a
circular shape may be employed for the injection port.
For example, an injection port having a rectangular
5   sectional shape may be employed for a front tooth, and
an injection port having an elliptical sectional shape
may be employed for a back tooth. As shown in FIG. 6,
when a plurality of injection ports are prepared at the
nozzle distal end portion, a plurality of teeth may be
10   simultaneously measured.

The distal end portion 34b of the nozzle 34 may be
integrated with the grip 34a. However, the distal end
portion 34b may be detachably separated from the grip
34a. When the distal end portion 34b is separated, it
15   may easily be detached from the grip 34a and subjected
to a process such as cleaning. To change the sectional
shape of the injection port of the nozzle and the shape
of the nozzle distal end portion, the distal end of the
nozzle may be covered with a cap having a predetermined
20   structure.

The control mechanism 41 may control the pressure
of the gas compressed by the fluid compressor 31 to
a predetermined pressure. The predetermined pressure
need not always be set to one value, and may be set
25   to various pressure values in accordance with the state
of the tooth, the age of the patient (adult or child),
the purpose of inspection, and the like. To set the

injection state of the gas to be injected from the valve 32 to a predetermined state, the controller 37 which ON/OFF-controls the valve 32 may adjust the number of times of injection, the injection timing, and the like. The controller 37 may be installed independently. Alternatively, it may be incorporated in the control mechanism 41.

The sensor 35 detects the movement of the tooth 28 that vibrates upon receiving an impact force from the gas injected from the distal end of the nozzle 34. An amplitude value as the displacement amount of the tooth, the period of vibration as the displacement time, the subsidence state of the vibration, or the like may be detected as the movement of the tooth. As for the sensor 35, a sensor which detects a change in air vibration such as a sonic wave or ultrasonic wave, or a change in electrostatic capacitance between the injection port and the tooth surface to detect the displacement state of the tooth may be used.

A sonic wave may suitably be used to detect a slow movement or very small fluctuation of a tooth. When a change in electrostatic capacitance is used, a simple sensor may be used, and the apparatus may easily be manufactured. A sensor using light is most preferable. In this case, a tooth is irradiated with light. The displacement state of the tooth may be detected on the basis of the phase shift or intensity of the

reflected light.

A laser is preferably used as an incident light, though a light from a xenon lamp or LED may also be used. In this embodiment, a sensor using a laser (to be referred to as a "laser sensor" hereinafter) will be described. The laser sensor 35 may be arranged at the distal end of the nozzle 34 of the injection mechanism 43, as shown in FIG. 4. Alternatively, as shown in FIG. 5, the laser sensor 35 may be arranged at the outer periphery or inner periphery (not shown) of the nozzle 34. One or a plurality of sensors 35 may be arranged. When a plurality of sensors are arranged, different positions of a tooth to be inspected may be measured. Such measurement is useful to detect the three-dimensional variation of a tooth and diagnose a partial pathological portion. If a plurality of sensors are to be used, four sensors are preferably arranged from the viewpoint of increasing the reliability and accuracy of measurement.

A light from the sensor points a surface of the tooth under inspection. Hence, the position at which the fluid injected from the nozzle distal end is injected to the tooth may be visually recognized. According to the embodiment of the present invention, since the tooth need not be hit with a hammer, inspection may be done at an operator's desired position without causing any hammering position error

due to a device movement.

FIG. 4 is a front view of the distal end portion
of the nozzle 34. The injection port 38 which injects
the gas is provided almost at the central portion of
the distal end portion of the nozzle 34. The four
laser sensors 35 may be arranged around the injection
port. Each laser sensor 35 irradiates the tooth with a
laser beam and receives the laser beam reflected by the
tooth. When, for example, the phase of the laser beam
with which the tooth is irradiated is compared with the
phase of the received laser beam, the distance between
the tooth and the sensor may be obtained on the basis
of the phase shift. When the distance is obtained,
the movement of the vibrating tooth may be detected.
The obtained distance may also be used to calculate the
degree of reduction of the pressure of the injected
gas. The laser sensor may also obtain the distance
from the intensity of the reflected light. The laser
sensor may also detect the movement of the tooth on the
basis of a change in intensity of reflected light.

A tooth mobility calculation mechanism (arithmetic
device) 40 calculates the acceleration and tooth
mobility when the tooth moves. Conventionally, the
acceleration of a tooth that moves is measured by
bringing the hammer distal end into direct contact
with the tooth. According to the present invention,
however, the acceleration may be calculated from the

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displacement amount and displacement time of a tooth
without touching the tooth. Hence, operation error by
the operator may be reduced, and a more accurate tooth
mobility than that in the conventional apparatus may be
5   calculated.

In this embodiment, the tooth vibrates upon
receiving an impact from the pressurized gas injected
from the nozzle 34. The displacement amount and
displacement time of the tooth are measured by the
10   sensor 35. Measurement data related to the tooth
displacement measured by the sensor 35 is input to
the arithmetic device 40 through an A/D converter 16.
The arithmetic device calculates the A/D-converted
measurement data to calculate the tooth mobility of the
15   tooth. The tooth mobility calculation method will be
described below.

Let F be the pressure of the fluid, x be the
displacement amount of the tooth, and k be the modulus
of elasticity of the gingiva. Then, they have a
20   relation

$$F = -k \cdot x \qquad (1)$$

Since the pressure F has a known value, and the
displacement amount x is the measurement result, the
modulus k of elasticity may be obtained. However, the
25   modulus k of elasticity changes in accordance with the
pressurizing position on the tooth. More specifically,
as the pressurizing position separates from the root

of tooth, the displacement amount increases, and
therefore, the modulus k of elasticity becomes small.

The time of vibration of the tooth, i.e., the
displacement time is given by

$$t = \pi (m/k)^{1/2} \tag{2}$$

where t is the displacement time, and m is the mass of
the tooth and gingiva. The displacement time t is
obtained by measurement. The mass m has a predeter-
mined value for the same object to be inspected.

When equations (1) and (2) are combined, the
modulus k of elasticity is erased, and a relation

$$x/t^2 = -F/m\pi^2 \tag{3}$$

is obtained. The left side of equation (3) indicates
the acceleration. As is apparent from equation (3),
the acceleration is proportional to the applied force
F. Hence, the acceleration may be calculated from the
displacement amount and displacement time.

As described above, to obtain the acceleration,
the force applied to the tooth, i.e., the pressure
value of the fluid is necessary. However, since the
nozzle 34 which injects the fluid is separated from
the tooth 28, the pressure of the injected fluid may
decrease by some extent. To cope with this, in the
present invention, the distance between the injection
nozzle 34 and the tooth surface 28 is measured by a
sensor in advance. Then, the pressure that is actually
applied to the tooth may be calculated. The calculated

pressure is evaluated together with the calculated acceleration, as described above, and expressed as a tooth mobility.

The calculated acceleration and tooth mobility of the tooth may be stored in a storage device 22 of the control mechanism 41 and also displayed on a display device 23. The tooth mobility of the tooth may also be printed on a paper sheet by a printer 25.

A method of measuring the tooth mobility of a tooth using the tooth mobility measuring apparatus 30 according to the embodiment of the present invention shown in FIG. 3 will be described. Referring to FIG. 3, a pressurized gas is formed by the fluid compressor 31. The pressure of the pressurized gas is controlled to a predetermined value by the control mechanism 41. The temperature of the pressurized gas is controlled to a predetermined value by a temperature adjusting mechanism 45. The operator brings the distal end portion 34b of the nozzle 34 close to the central portion of a tooth as an inspection object of a patient who is sitting on a chair. A portion to be measured on the tooth may be marked in advance. At this time, the distal end portion 34b of the nozzle 34 is preferably held at a right angle with respect to the central portion without touching the tooth to be measured.

As the position of the tooth to be inspected goes deep into the mouth, it becomes more difficult to

locate the distal end of the nozzle at the central

portion of the tooth. If a back tooth is to be

measured, for example, the nozzle distal end portion

may the covered with an L-shaped cap. In addition,

5   when light is output from the sensor 35 arranged at the

distal end portion 34b of the nozzle 34, the impact

position of the fluid injected from the nozzle 34 may

be visually recognized. Hence, even for a tooth such

as a back tooth that is hard to inspect, the injection

10   port may easily be located to face the tooth to be

inspected.

The operator operates the switch 36 on the nozzle

34 by hand or a foot switch to turn it on. With this

switching, control by the controller 37 starts, and

15   the valve 32 in the nozzle 34 opens/closes in

a predetermined way. While the valve 32 is open in

a predetermined way, the gas sent from the fluid

compressor 31 trough the tube 33 is injected from the

injection port 38 of the nozzle 34 to the central

20   portion of the tooth in, e.g., a pulse-like pattern.

The tooth moves upon injection. The sensor 35

detects predetermined items such as the maximum

displacement amount and displacement time of the moving

tooth and the distance from the injection port 38 to

25   the tooth to be inspected. The pieces of detected

information are amplified by an amplifier 11, converted

into digital data by the A/D converter 16, then input

to the arithmetic device 40. The arithmetic device
may also receive the pressure information of the
pressurized gas or the distance between the nozzle
and the tooth from the control mechanism 41 or data
related to the gas injection state from the controller
37. The arithmetic device 40 calculates the tooth
mobility on the basis of the input data. The tooth
mobility as the measurement result may be stored in
the storage device 22 of the control mechanism 41 or
displayed on the display device 23 as a numerical
value or a graph. The measurement result may also be
printed on a paper sheet by the printer 25, as needed.
Alternatively, the result may be output as sound by
a sound device 24.

The tooth mobility of the tooth may be measured in
the above-described manner. This measurement may be
executed for one tooth either once or a plurality of
times. When the measurement is executed a plurality
of times, a plurality of measurements may be executed
in a short time by causing the controller 37 to
intermittently continuously open/close the valve 32.
When the measurement is executed a plurality of times,
the same pressurized gas injection condition may be
applied each time. Alternatively, the pressurized
gas injection condition may be automatically changed
every time by the controller 37. When measurement is
executed while changing the pressurized gas injection

condition every time, the tooth mobility may be measured by selecting the optimum condition for the tooth from the different conditions. The above-described inspection method may be executed not only for one tooth but also simultaneously for a plurality of teeth. Even, e.g., an artificial tooth fixed by a bridge may also be simultaneously inspected.

When the above tooth mobility measuring operation is performed, the tooth mobility measuring apparatus 30 may have a notification mechanism (sound device 24) which notifies the operator of the end of measurement by, e.g., sound (e.g., beep). If the notification mechanism outputs no sound that indicates the end, the operator may easily recognize that the measurement is not ended yet and decide to start measurement again.

According to the embodiment of the present invention, when a fluid is used, a tooth may be moved without directly touching it. When a fluid is used, the impact force to be applied to the tooth may have an accurate value. In addition, by the method of calculating the acceleration, the tooth mobility may be measured without bringing the sensor into contact with the tooth. Since the apparatus need not be brought into direct contact with the tooth, it may easily be disinfected, unlike the conventional apparatus that requires sterilization.

In the embodiment of the present invention, the

pressure of the pressurized fluid to be injected or the pressure of suction may be adjusted by the controller 37. When a tooth with high tooth mobility is to be inspected, the pressure may be reduced. Hence, the
5   measurement may be executed while easing the pain on the patient. In addition, the temperature of the pressurized fluid may also be adjusted. Hence, the measurement may be executed while easing the pain or discomfort of the patient.

10   Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various
15   modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.